AD-A036 436 OHIO STATE UNIV COLUMBUS ELECTROSCIENCE LAB F/G 9/5
PARAMETRIC STUDIES OF AN ADAPTIVE ARRAY FOR AM SIGNALS.(U)
JAN 77 L C CHAN, R T COMPTON N00019-76-C-0195
UNCLASSIFIED ESL-4326-4 NL

1 OF 1
AD-A
036 436

END
DATE
FILMED
4-4-77
NTIS

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

AD-A036 436

PARAMETRIC STUDIES OF AN ADAPTIVE ARRAY FOR AM SIGNALS

Ohio State University
Columbus

January 1977

NOTICE

[illegible] drawings, specifications, or other data are [illegible] other than in connection with a definitely [illegible] procurement operation, the United States [illegible] no responsibility nor any obligation [illegible] the fact that the Government may have formulated, [illegible] supplied the said drawings, specifications, [illegible] is not to be regarded by implication or otherwise as [illegible] licensing the holder or any other person or corporation, [illegible] any rights or permission to manufacture, use, or sell [illegible] invention that may in any way be related thereto.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): PARAMETRIC STUDIES OF AN ADAPTIVE ARRAY FOR AM SIGNALS	5. TYPE OF REPORT & PERIOD COVERED: Final Report 12/1/75 - 11/30/76
	6. PERFORMING ORG. REPORT NUMBER: ESL 4326-4
7. AUTHOR(s): L.C. Chan and R.T. Compton, Jr.	8. CONTRACT OR GRANT NUMBER(s): Contract N00019-76-C-0195
9. PERFORMING ORGANIZATION NAME AND ADDRESS: The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering, Columbus, Ohio 43212	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: Department of the Navy, Naval Air Systems Command, Washington, D.C. 20361	12. REPORT DATE: January 1977
	13. NUMBER OF PAGES: 35
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Adaptive Array
Amplitude Modulation
Interference Rejection

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents extensive simulation results for an adaptive array with phase-switched AM signals. The results indicate that the array can provide suitable protection for these AM signals against CW interference. Interference rejection is slightly poorer at certain critical frequencies. However, the system performance is nevertheless still adequate at these frequencies for reliable communications.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

TABLE OF CONTENTS

		Page
I.	INTRODUCTION	1
II.	THE SIMULATED SYSTEM AND THE PRESENTATION FORMAT OF THE RESULTS	2
III.	EFFECT OF THE INTERFERENCE FREQUENCY ω_I	4
IV.	EFFECT OF THE SWITCHING FREQUENCY ω_p	8
V.	EFFECT OF THE DESIRED SIGNAL SIDEBAND FREQUENCE ω_m	11
VI.	EFFECT OF THE MODULATION INDEX m	14
VII.	EFFECT OF THE FEEDBACK LOOP GAIN CONSTANT G_D	17
VIII.	EFFECT OF THE INPUT SIGNAL-TO-INTERFERENCE RATIO SIR_{IN}	20
IX.	WORST CASES	23
X.	EFFECT OF SIR_{IN} IN A TYPICAL WORST CASE	27
XI.	SUMMARY AND CONCLUSIONS	27
REFERENCES		30

I. INTRODUCTION

This report is a continuation of an earlier report[1] on an adaptive array technique for AM signals. In that report, a method of phase modulating an AM signal was described that makes it possible for the adaptive array to distinguish this signal from interference. The general system concept was described and a few initial results were shown.

In this report, we continue with more detailed simulation studies showing the effects of various system parameters on the performance of such an array. The system simulated here is identical to that described in Reference [1], and it is suggested that the reader review that report before attempting to read this one.

In the previous report[1], the following quantities had been defined:

$$\left\{\begin{aligned}
d(t) &= \text{desired signal} = A(1 + m\cos\omega_m t)\cos\omega_c t \\
i(t) &= \text{interference signal} = B\cos\omega_I t \\
r(t) &= \text{reference signal} = C\,p(t)\cos\omega_c t \\
p(t) &= \text{square wave with switching frequency } \omega_p \\
\omega_c &= \text{carrier frequency} \\
\omega_I &= \text{interference frequency} \\
\omega_m &= \text{desired AM signal sideband frequency} \\
m &= \text{modulation index of the desired AM signal} \\
\theta_D &= \text{direction of arrival of the desired signal} = 0^\circ \\
\theta_I &= \text{direction of arrival of the interference signal} \\
T &= \text{sampling period of the simulation process} = 2.5 \times 10^{-6}\ \text{sec} \\
G_D &= \text{digital feedback loop gain constant} = 2K_D
\end{aligned}\right. \tag{1}$$

In this report we investigate the effects on array performance of varying the following six parameters:

a. Interference frequency ω_I
b. Switching frequency ω_p
c. Desired signal sideband frequency ω_m
d. Modulation index m
e. Feedback loop gain constant G_D
f. Input signal to interference ratio (SIR_{IN}).

The effects of the first four parameters will be studied by varying each one individually. Also, since the case where $\omega_p = |\omega_\Delta| = |\omega_I - \omega_c|$ is a worse-case condition[1], for some simulations ω_p and ω_Δ will be varied simultaneously to satisfy this equality at different values. In addition, SIR_{IN} and G_D will be varied simultaneously, since both affect two parameters, namely the feedback loop bandwidth and time constant.

Section II gives a list of the parameter values chosen in the simulated system, and explains the presentation format of the results. Sections III, IV, V, VI, VII and VIII study the effects of ω_I, ω_p, ω_m, m, G_D and SIR_{IN}, respectively, on system performance. Section IX considers the array performance in the worst case situations for $\omega_p = |\omega_\Delta|$. Section X studies the effect of SIR_{IN} in these situations. Section XI presents a summary and the conclusions of the study.

II. THE SIMULATED SYSTEM AND THE PRESENTATION FORMAT OF THE RESULTS

The system simulated, as in the companion report[1], is a two-element array with isotropic elements spaced a half wavelength apart at frequency ω_c. The simulation parameters have the following values:

$$
(2) \quad \begin{cases}
\omega_c = 2\pi\ (100 \times 10^3)\ \text{rad/sec} \\
\omega_I = 2\pi\ (100 \times 10^3)\ \text{rad/sec} \\
\omega_m = 2\pi\ (8 \times 10^3)\ \text{rad/sec} \\
\omega_p = 2\pi\ (20 \times 10^3)\ \text{rad/sec} \\
A = 0.750 \\
B = 10. \\
C = 1. \\
m = 0.333 \\
T = 2.5 \times 10^{-6}\ \text{sec}. \\
\theta_D = 0^\circ \\
\theta_I = 60^\circ \\
G_D = 0.0003
\end{cases}
$$

This set of parameters will be considered as the "standard set" in the simulations. In the sections that follow, only the particular parameters under study in each section are varied. All others have the values above.

Five quantities have been calculated from the simulated results to characterize the array responses.† They are

a. GAIN,θ_D: The magnitude of the array factor in the desired-signal direction and at the desired-signal carrier frequency.

b. PHASE,θ_D: Phase of the array factor in the desired-signal direction and at the desired-signal carrier frequency.

c. GAIN,θ_I: The magnitude of the array factor in the interference-signal direction and at the interference-signal frequency.

d. GAIN RATIO: The ratio of GAIN,θ_D, to GAIN,θ_I, i.e., the improvement in signal-to-interference ratio due to the adaptive array as compared to an isotropic antenna.

e. SIR_{OUT}: The output signal-to-interference ratio.

These quantities, as discussed in the companion report[1], are functions of the array weights. Since the steady state array weights contain both constant and time-varying terms (weight jitter), so do these quantities. In the simulation results below, we shall present both the average value and the amount of fluctuation of these quantities.

Each quantity (such as GAIN,θ_D) fluctuates between a maximum and a minimum value, once the initial weight transients have ended. For each quantity, we define the

$$\text{AVERAGE} \triangleq \frac{\text{MAXIMUM}+\text{MINIMUM}}{2}$$

and the

$$\text{FLUCTUATION} \triangleq \frac{\text{MAXIMUM}-\text{MINIMUM}}{2}$$

The AVERAGE will be shown for all the quantities in (a) - (e); the FLUCTUATION will be shown for the first three.

---

† These quantites were defined in [1].

As discussed previously[1], averaged values and the amount of fluctuation of these quantities depend heavily on the spectral components of the three correlation products $C_{DR}(t)$, $C_{IR}(t)$ and $C_{ID}(t)$ inside the feedback loop bandwidth.† Hence we show the Fourier transforms,

$$C(\omega) = \frac{1}{2\pi}\int_{-\infty}^{\infty} C(t)\, e^{-j\omega t}\, dt$$

of these correlation products along with the simulation results.

III. EFFECT OF THE INTERFERENCE FREQUENCY ω_I

The Fourier transforms of the three correlation products $C_{DR}(t)$, $C_{IR}(t)$ and $C_{ID}(t)$ are shown in Fig. 1a (plotted for a typical case, $\omega_I = 2\pi\ (90 \times 10^3)$ rad/sec). Array responses as ω_I is varied are shown in Fig. 1b.

The array performance is summarized as follows.

(a) GAIN, θ_D

(A) AVERAGE: Essentially constant except when ω_I approaches the worst case values of $2\pi\ (80 \times 10^3)$ rad/sec where $\omega_p = |\omega_\Delta| = 2\pi\ (20 \times 10^3)$ rad/sec, where a minimum occurs.

(B) FLUCTUATION: Generally decreases in the vicinity of the three critical frequencies where one or more of the components in $C_{IR}(\omega)$ and $C_{ID}(\omega)$ become DC components. The three critical frequencies are:

1) $\omega_I = 2\pi\ (80 \times 10^3)$ rad/sec. This corresponds to the worst case where $|\omega_\Delta| = \omega_p$. The components of $C_{IR}(\omega)$ and $C_{ID}(\omega)$ at $\omega_p - |\omega_\Delta|$ are at dc, and thus do not contribute to the fluctuation.

---

† $C_{DR}(t) = D(t)R^*(t)$

$C_{IR}(t) = I(t)R^*(t)$

$C_{ID}(t) = I(t)D^*(t)$

where the uppercase letters denote the complex forms of the corresponding lowercase letter signals.

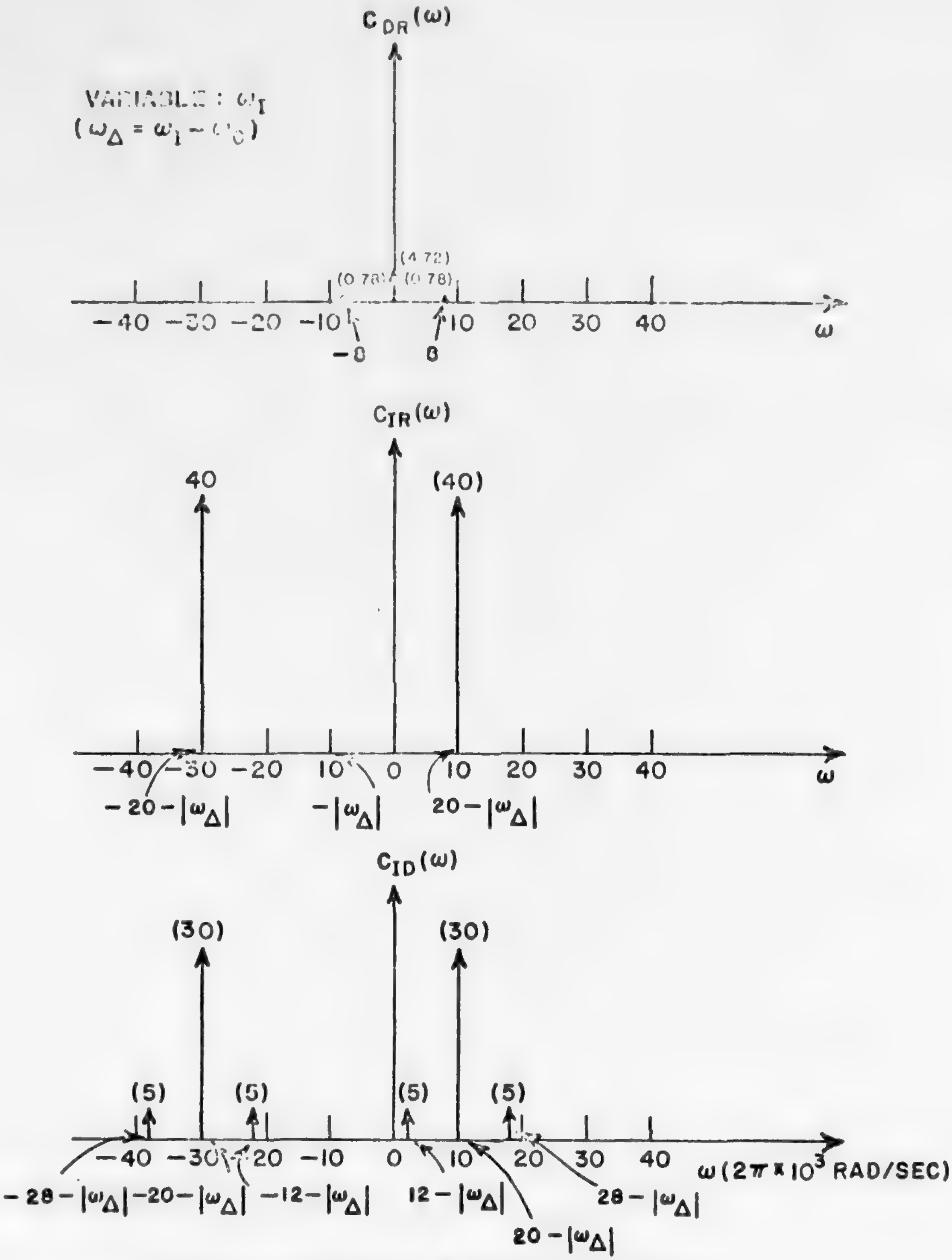

Fig. 1a. Correlation products (ω_I varying).

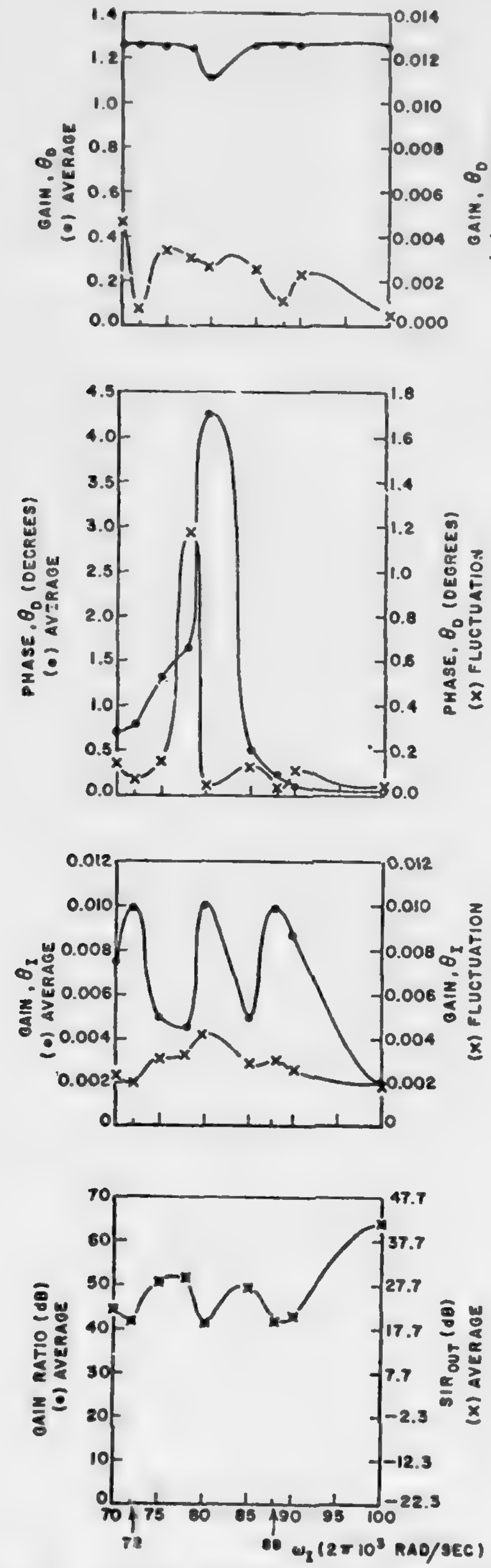

Fig. 1b. Array responses (ω_I varying).

2) and 3) $\omega_I = 2\pi\ (72 \times 10^3)$ and $2\pi\ (88 \times 10^3)$ rad/sec. These correspond to the two cases where $\omega_p - |\omega_\Delta| = \pm\omega_m = \pm 2\pi\ (8 \times 10^3)$ rad/sec. The components of $C_{ID}(\omega)$ at $28 - |\omega_\Delta|$ and $12 - |\omega_\Delta|$ become dc components.

The fluctuation decreases as ω_I approaches ω_C, for $|\omega_\Delta|$ approaches zero and the components which are closest to dc (and therefore contribute the most fluctuation) will move away from dc.

(b) PHASE, θ_D

(A) AVERAGE: The peak value occurs at the worst-case frequency $\omega_I = 2\pi\ (80 \times 10^3)$ rad/sec. However, no relative maximum occurs at the other two critical frequencies mentioned in (a).

(B) FLUCTUATION: A relative minimum occurs at each of the three critical frequencies.

(c) GAIN, θ_I

(A) AVERAGE: The peak values occur at all three critical frequencies.

(B) FLUCTUATION: A relative extremum occurs at each of the three frequencies; however only the one at $\omega_I = 2\pi\ (72 \times 10^3)$ rad/sec is a minimum the other two are maxima. These results illustrate a case in which the fluctuation increases even though one of the spectral lines goes to dc, a somewhat surprising result.

(d) GAIN RATIO AND SIR_{OUT} †

(A) AVERAGE: A relative minimum occurs at each of the three critical frequencies. The absolute minimum average level of SIR_{OUT} is 18.8 dB.

---

† SIR_{IN} does not depend on ω_I, so SIR_{OUT} and GAIN RATIO are related by a constant.

In general, as ω_I is varied, array performance is worse when the reference and desired signals are more correlated with the interference, i.e., when the major components of the spectral products are within the feedback loop bandwidth. The worst performance occurs when $\omega_p = |\omega_\Delta|$. However, the interference suppression and the output signal-to-interference ratio appear to be satisfactory for reliable AM communications for all values of ω_I.

IV. EFFECT OF THE SWITCHING FREQUENCY ω_p

The Fourier transforms of the three correlation products are shown in Fig. 2a (plotted for $\omega_p = 2\pi\ (15 \times 10^3)$ rad/sec). Array responses as ω_p is varied are given in Fig. 2b.

The array performance is summarized as follows.

(a) <u>GAIN, θ_D</u>

(A) AVERAGE: Increases monotonically as ω_p increases. Note that the case of ω_p=0 represents an unrealistic case where the system is actually uncoded and also $\omega_p = |\omega_\Delta| = 0$.

(B) FLUCTUATION: A relative minimum occurs when $\omega_p = \omega_m = 2\pi\ (8 \times 10^3)$ rad/sec. In this case the two components of $C_{ID}(\omega)$ at $-\omega_p + \omega_m$ and $\omega_p - \omega_m$ become dc components.

(b) <u>PHASE, θ_D</u>

(A) AVERAGE: Decreases monotonically as ω_p increases.

(B) FLUCTUATION: Very small for all values of ω_p. No relative extremum occurs when $\omega_p = \omega_m$.

(c) <u>GAIN, θ_I</u>

(A) AVERAGE: A minimum occurs when $\omega_p = \omega_m$. This is a case when the desired and interference signal product has a dc component.

(B) FLUCTUATION: Smallest when ω_p equals ω_m and for larger ω_p.

(d) <u>GAIN RATIO AND SIR_{OUT}</u>

(These two parameters differ by only a scalar constant for all values of ω_p.)

(A) AVERAGE: Increases as ω_p increases except in the $\omega_p = \omega_m$ region. Maximum occurs when $\omega_p = \omega_m$.

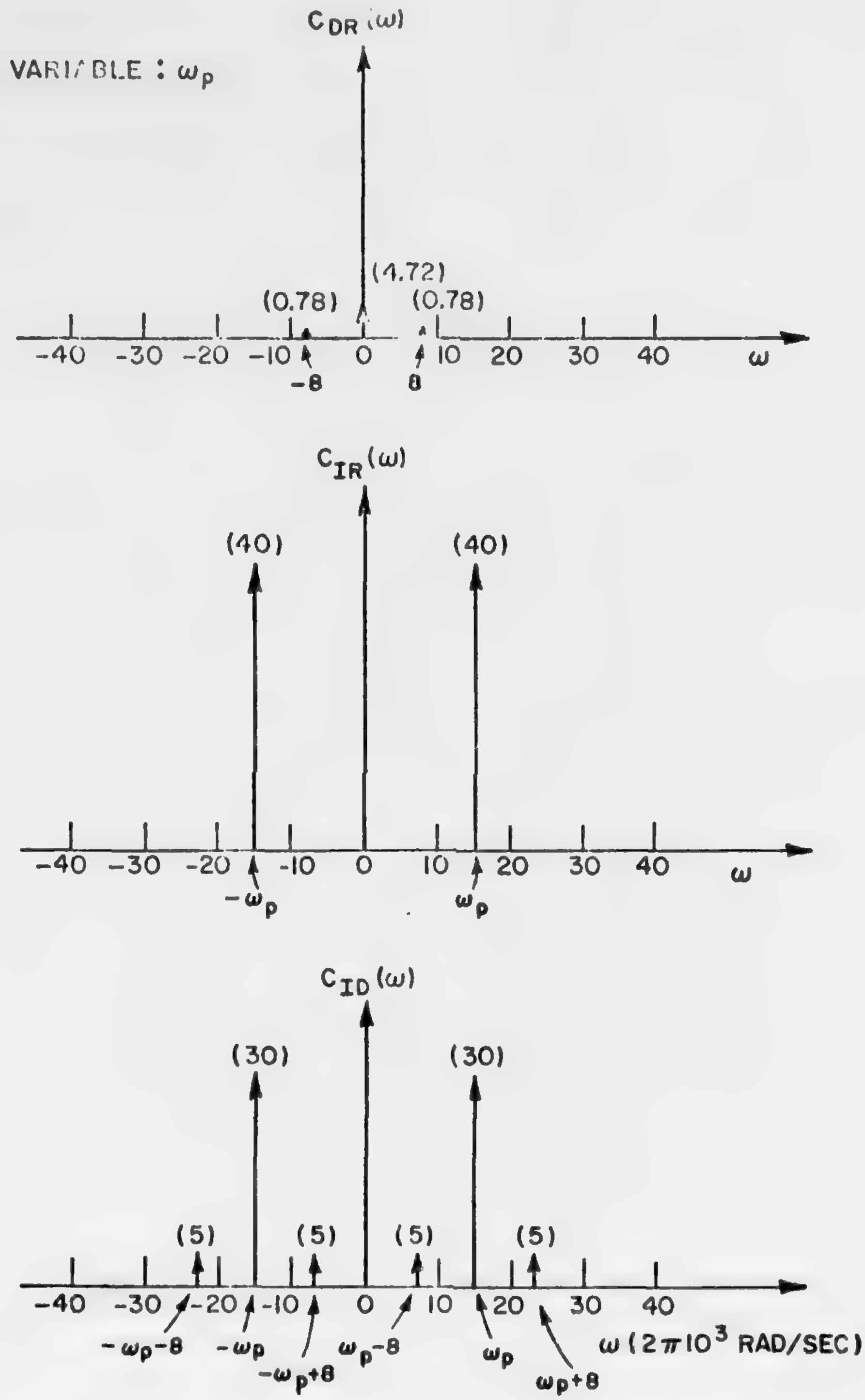

Fig. 2a. Correlation products (ω_p varying).

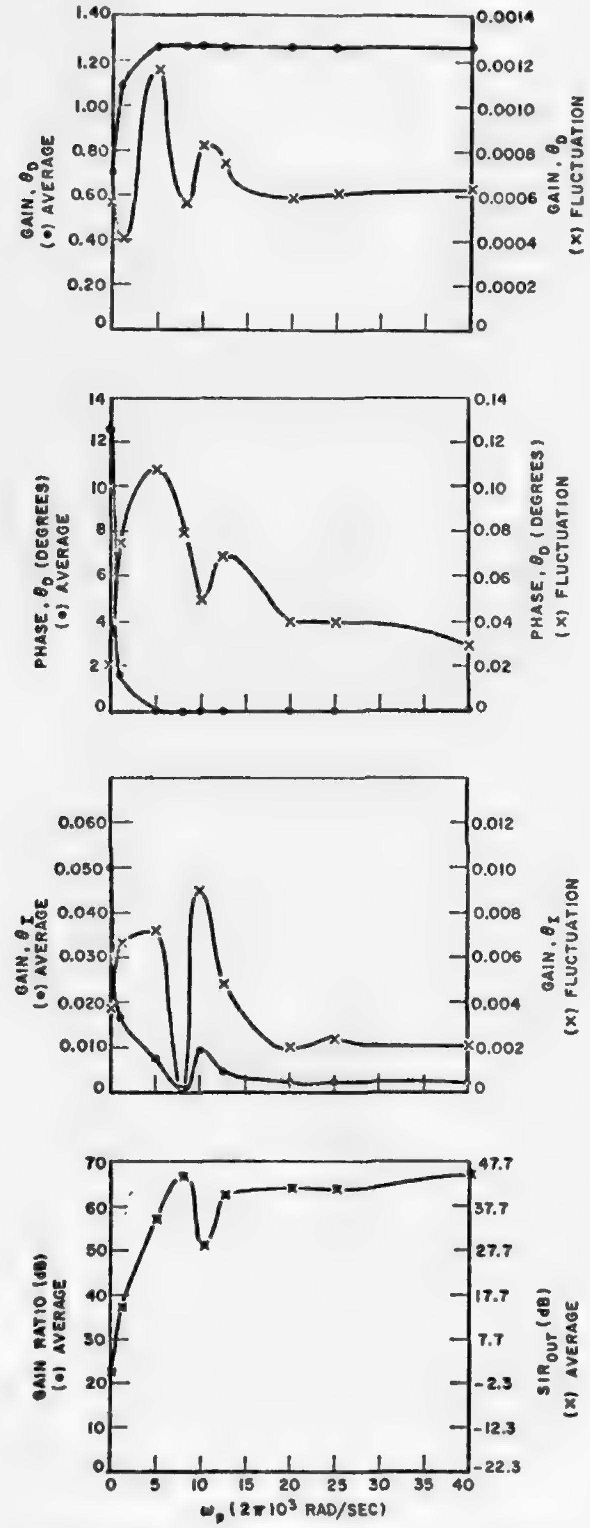

Fig. 2b. Array responses (ω_p varying).

In general, in varying ω_p the array performance is better for larger ω_p; however, small values of ω_p yield satisfactory array performance.

V. EFFECT OF THE DESIRED SIGNAL SIDEBAND FREQUENCY ω_m

The Fourier transforms of the three correlation products are shown in Fig. 3a (plotted for $\omega_m = 2\pi\ (5 \times 10^3)$ rad/sec). Array responses as ω_m is varied are given in Fig. 3b.

The array performance is summarized as follows.

(a) GAIN,θ_D

(A) AVERAGE: Minimum occurs at ω_m=0. As ω_m increases the average level of GAIN,θ_D stays fairly constant for all values of ω_m. Note that at ω_m=0, the power in the desired AM signal is larger than for $\omega_m \neq 0$[2].

(B) FLUCTUATION: Minimum occurs at ω_m=0. When ω_m increases the level of oscillation increases to a relative maximum and then decreases for larger ω_m. The minimum occurs at ω_m=0 because the two components of $C_{DR}(\omega)$ at $\pm\omega_m$ become dc components and the two components of $C_{ID}(\omega)$ which are closest to dc move farther away from dc. As ω_m increases, the two components in $C_{DR}(\omega)$ move away from dc while the two in $C_{ID}(\omega)$ move closer to dc. At $\omega_m = 2\pi\ (10 \times 10^3)$ rad/sec, the contributions from these four components combine to form a maximum in the fluctuation of GAIN,θ_D. As ω_m increases further the two components in $C_{DR}(\omega)$ move farther away from dc while the two in $C_{ID}(\omega)$ become a dc component and thereby reduce the fluctuation.

(b) PHASE,θ_D

(A) AVERAGE: Minimum occurs at ω_m=0. The average of PHASE,θ_D fluctuates as ω_m increases. However the maximum average is less than 0.1°.

(B) FLUCTUATION: Similar to the behavior of the average.

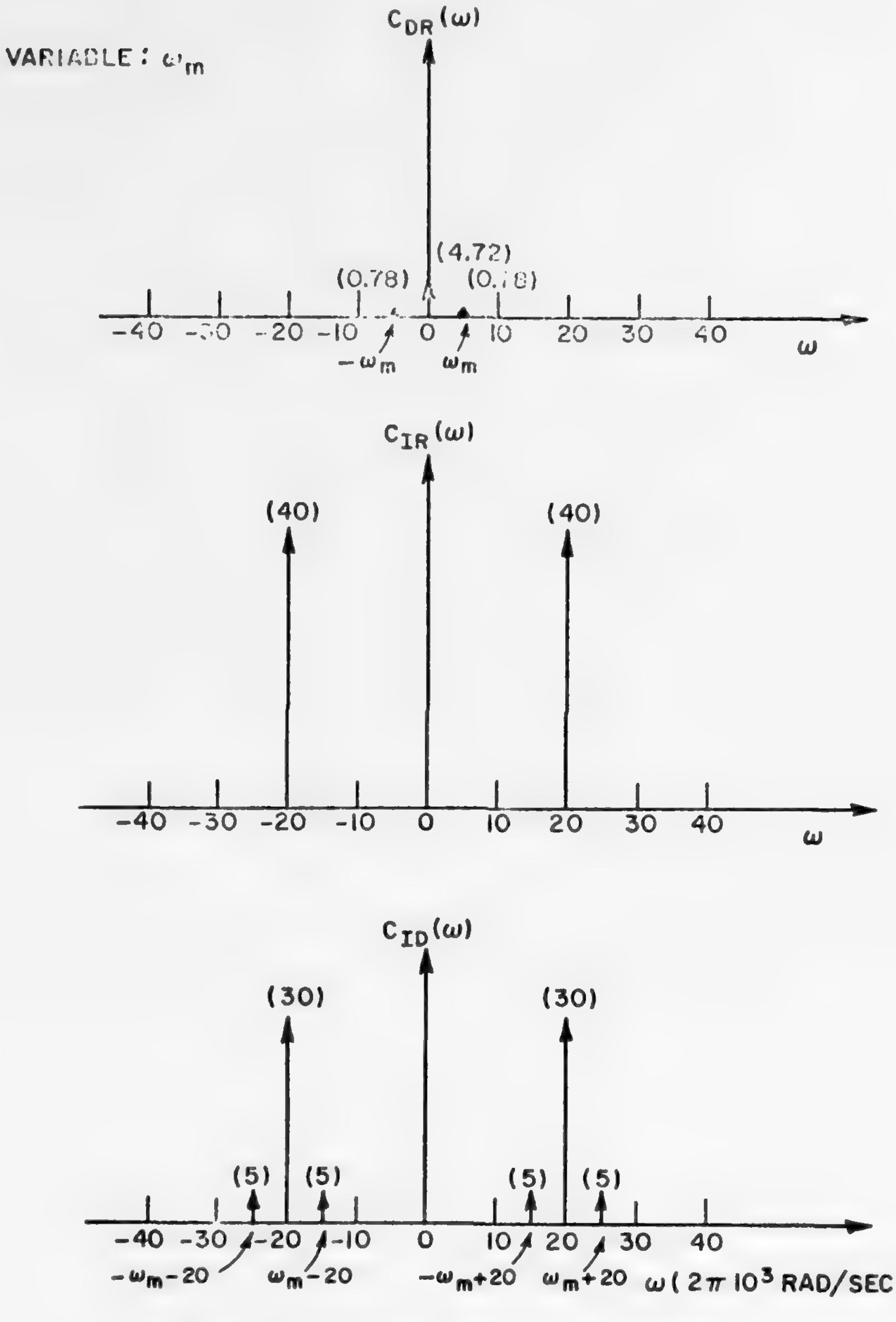

Fig. 3a. Correlation products (ω_m varying).

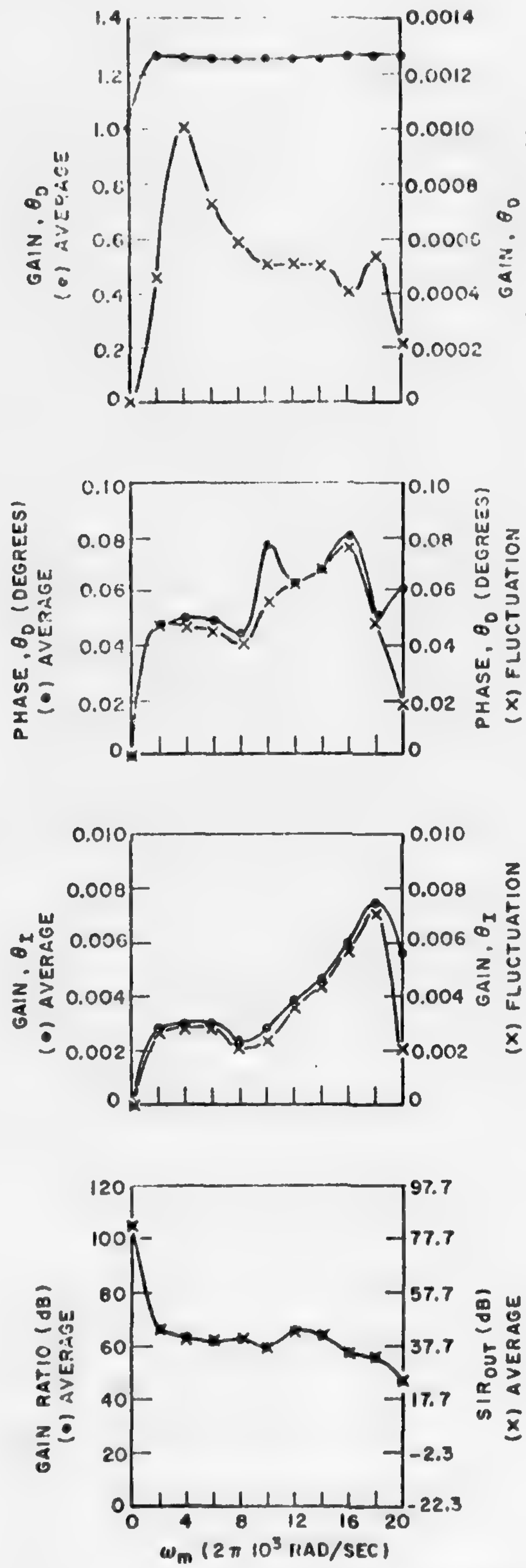

Fig. 3b. Array responses (ω_m varying).

(c) GAIN, θ_I

(A) AVERAGE: Minimum occurs when ω_m=0. The average of GAIN, θ_I increases as ω_m increases. The minimum occurs when ω_m =0, because at that frequency the desired and reference signals are perfectly correlated. Their correlation decreases as ω_m increases.

(B) FLUCTUATION: The minimum occurs when ω_m=0 or $\omega_m = 2\pi$ (20 x 10^3) rad/sec. At ω_m=0, the two components of $C_{DR}(\omega)$ become dc components while at $\omega_m = 2\pi$ (20 x 10^3) rad/sec the two components of $C_{ID}(\omega)$ becomes dc components.

(d) GAIN RATIO AND SIR_{OUT}

(The SIR_{IN} is the same for all values of ω_m (-22.3 dB) except for ω_m=0. At ω_m=0, SIR_{IN} = -20 dB.)

(A) Both GAIN RATIO and SIR_{OUT} decrease as ω_m increases.

In general, in varying ω_m, the array performance degrades as ω_m increases. Relative extrema occur in the quantities plotted at the critical frequencies (such as ω_m=0 or $\omega_m = 2\pi$ (20 x 10^3) rad/sec) when the components of one or more of the correlation products move to dc.

VI. EFFECT OF THE MODULATION INDEX m

The Fourier transforms of the various correlation products are shown in Fig. 4a. Array responses as m is varied are given in Fig. 4b.

Varying m affects the amount of power in the sideband components of $C_{DR}(\omega)$ and $C_{ID}(\omega)$.

The array performance is summarized as follows.

(a) GAIN, θ_D

(A) AVERAGE: Decreases as m increases. The power in the sidebands increases as m increases, causing the desired and reference signal to be less correlated.

(B) FLUCTUATION: Generally increases as m increases. Increasing the power in the desired signal has the effect of enlarging the feedback loop bandwidth and thereby increases the amount of fluctuation.

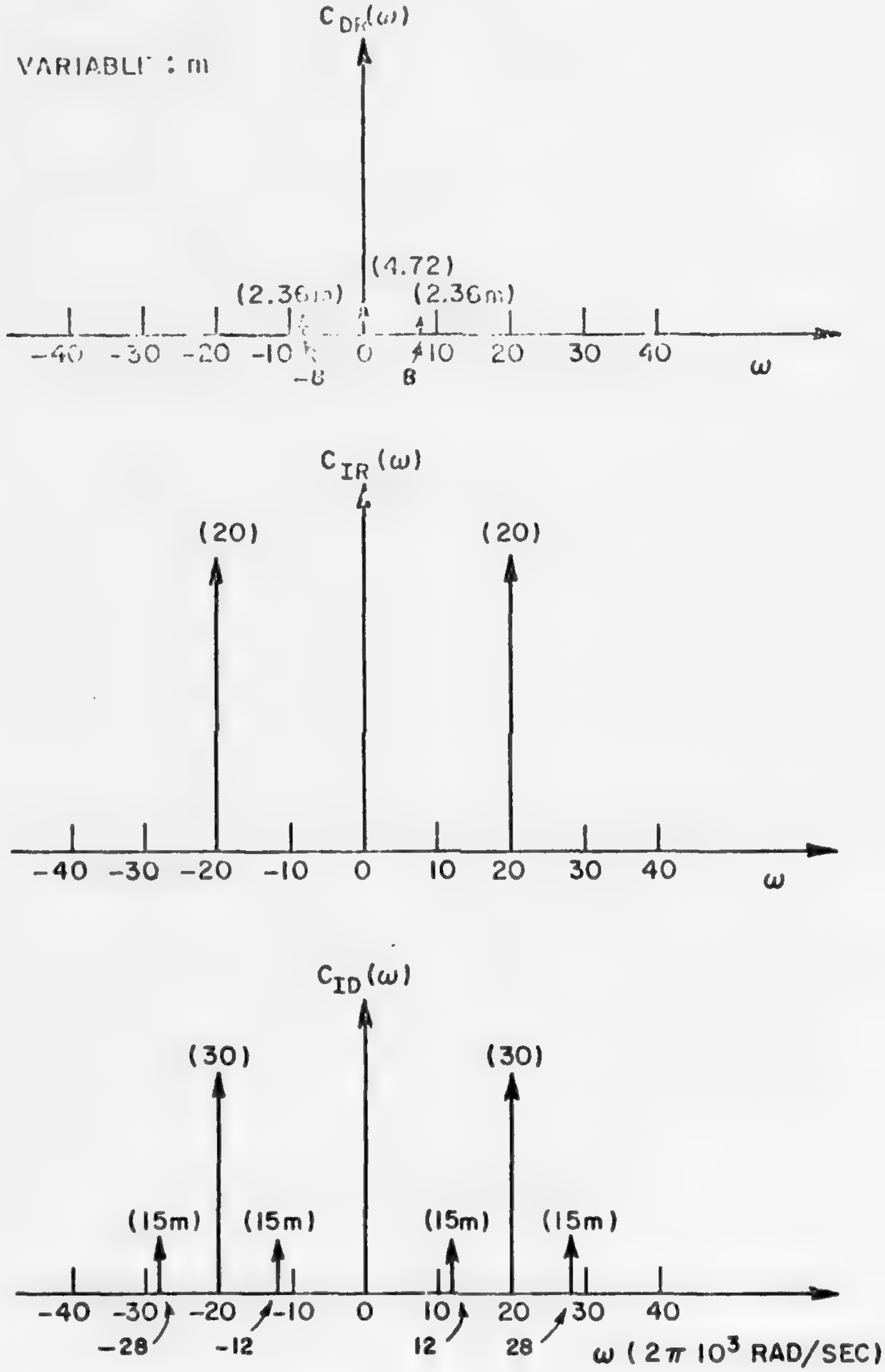

Fig. 4a. Correlation products (m varying).

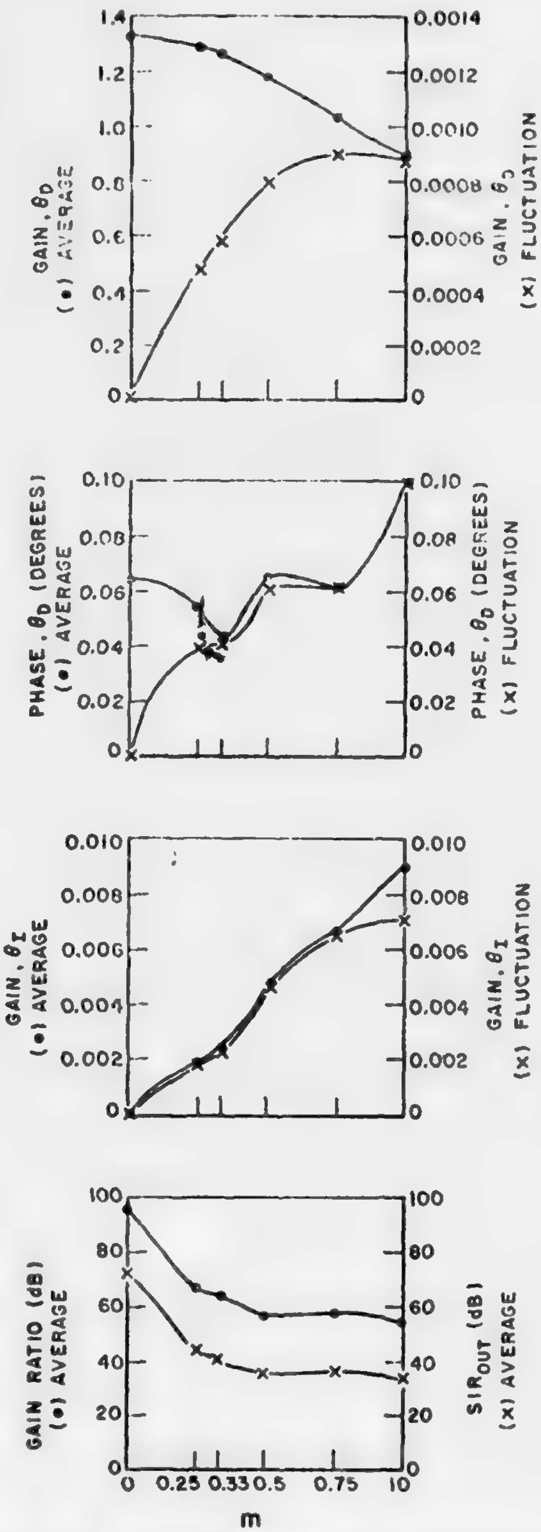

Fig. 4b. Array responses (m varying).

(b) PHASE, θ_D

(A) AVERAGE: Fluctuates as m varies. However, maximum phase level is less than 0.1°.

(B) FLUCTUATION: Increases as m increases.

(c) GAIN, θ_I

(A) AVERAGE: Increases as m increases.

(B) FLUCTUATION: Increases as m increases.

(d) GAIN RATIO AND SIR_{OUT}

(In this case, SIR_{IN} is not constant, and the two parameters are not related by a scalar constant. However from Fig. 4b it is obvious, as m increases, both quantities behave in a similar manner.)

(A) AVERAGE (both quantities): Decreases as m increases.

In general, as m increases, the desired and reference signals become less correlated and array performance degrades.

VII. EFFECT OF THE FEEDBACK LOOP GAIN CONSTANT G_D

The Fourier transforms of the three correlation products are shown in Fig. 5a. Array responses as G_D is varied are shown in Fig. 5b.

Note that varying G_D changes the bandwidth of the feedback loop. In Fig. 5b the control loop bandwidth B_D corresponding to the different values of G_D are also given.

The array performance is summarized as follows.

(a) GAIN, θ_D

(A) AVERAGE: Constant.

(B) FLUCTUATION: Increases as G_D increases.

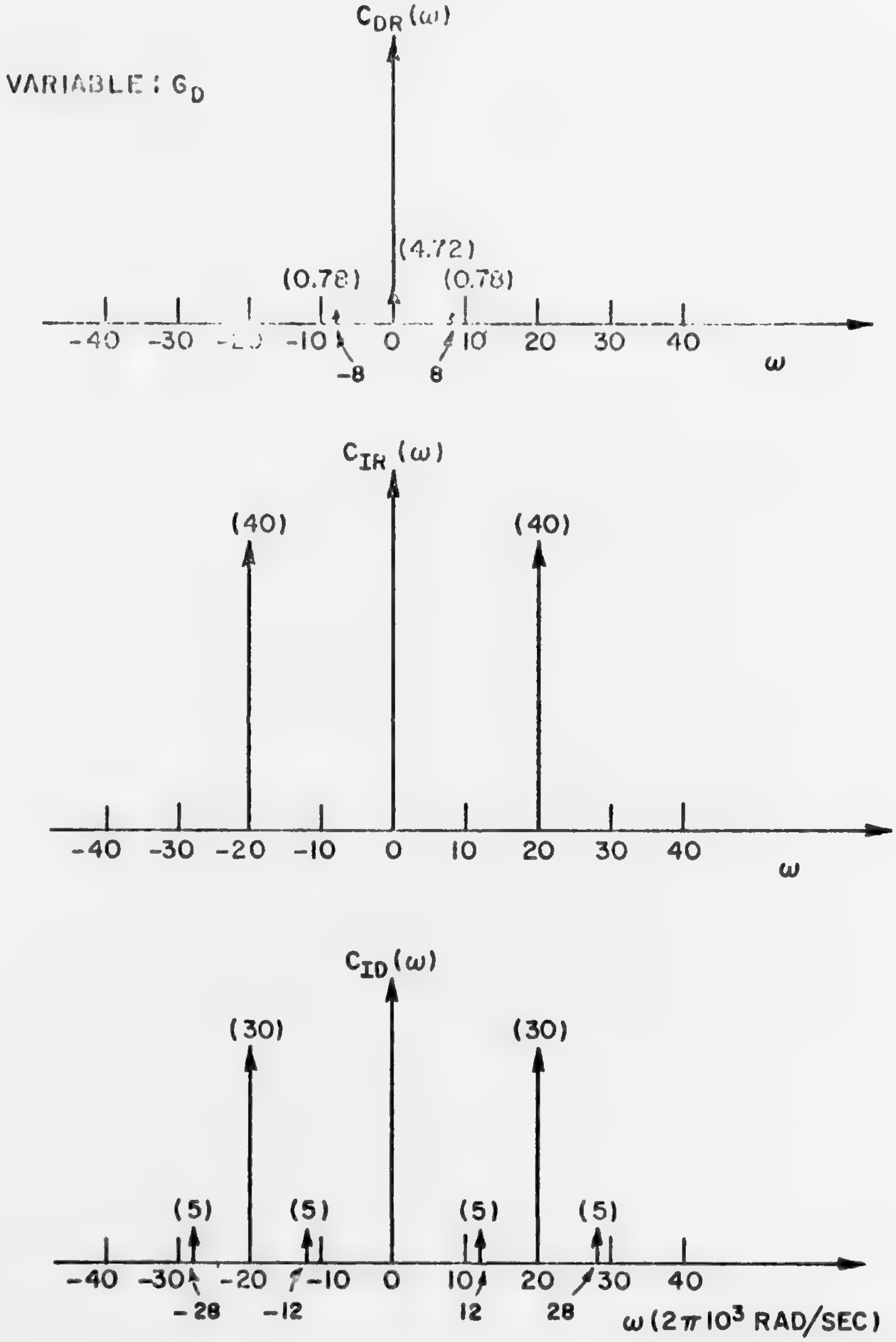

Fig. 5a. Correlation products (G_D varying).

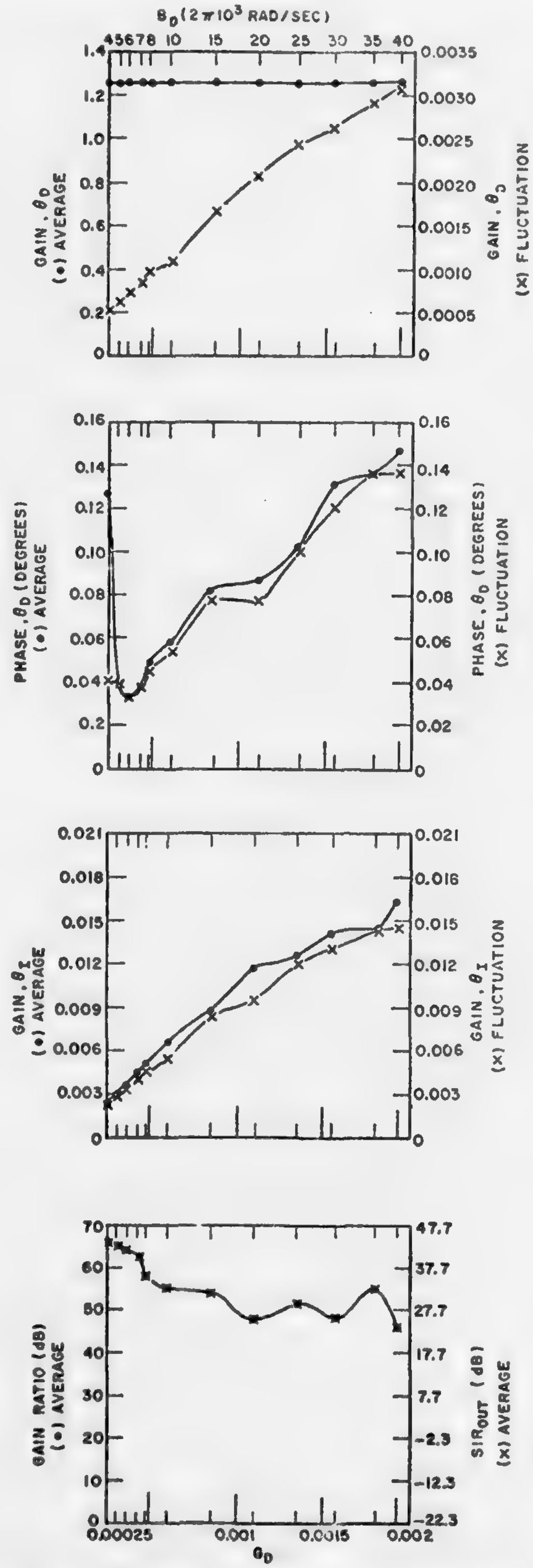

Fig. 5b. Array responses (G_D varying).

(b) PHASE, ϕ_D

(A) AVERAGE: Increases as G_D increases (except at small G_D values).

(B) FLUCTUATION: Increases as G_D increases.

(c) GAIN, θ_D

(A) AVERAGE: Increases as G_D increases.

(B) FLUCTUATION: Increases as G_D increases.

(d) GAIN RATIO AND SIR_{OUT}

(In this case, SIR_{IN} is constant and the two parameters differ only by a scalar constant.)

(A) AVERAGE: Generally decreases as G_D increases.

In general, the array performance degrades as G_D increases.

VIII. EFFECT OF THE INPUT SIGNAL-TO-INTERFERENCE RATIO SIR_{IN}

The Fourier transforms of the three correlation products are shown in Fig. 6a. Array responses are given in Fig. 6b. In these results, the amplitudes of the desired and reference signals are kept equal and the array gain constant G_D is varied simultaneously to maintain constant array feedback loop bandwidth as SIR_{IN} is varied.

The array performance is summarized as follows.

(a) GAIN, θ_D

(A) AVERAGE: For $SIR_{IN} \leq 0$ dB the average GAIN, θ_D increases as SIR_{IN} increases. For $SIR_{IN} > 0$ dB, it stays fairly constant. The above behavior can be explained as follows. When $SIR_{IN} \leq 0$ dB, the interference signal power is larger than the desired signal power and G_D has a low value. Hence the desired signal match to the reference signal becomes poorer. This poorer match results in a lower value of GAIN, θ_D. When $SIR_{IN} > 0$, the desired signal is the dominant term in the array output and a close match with the reference signal results.

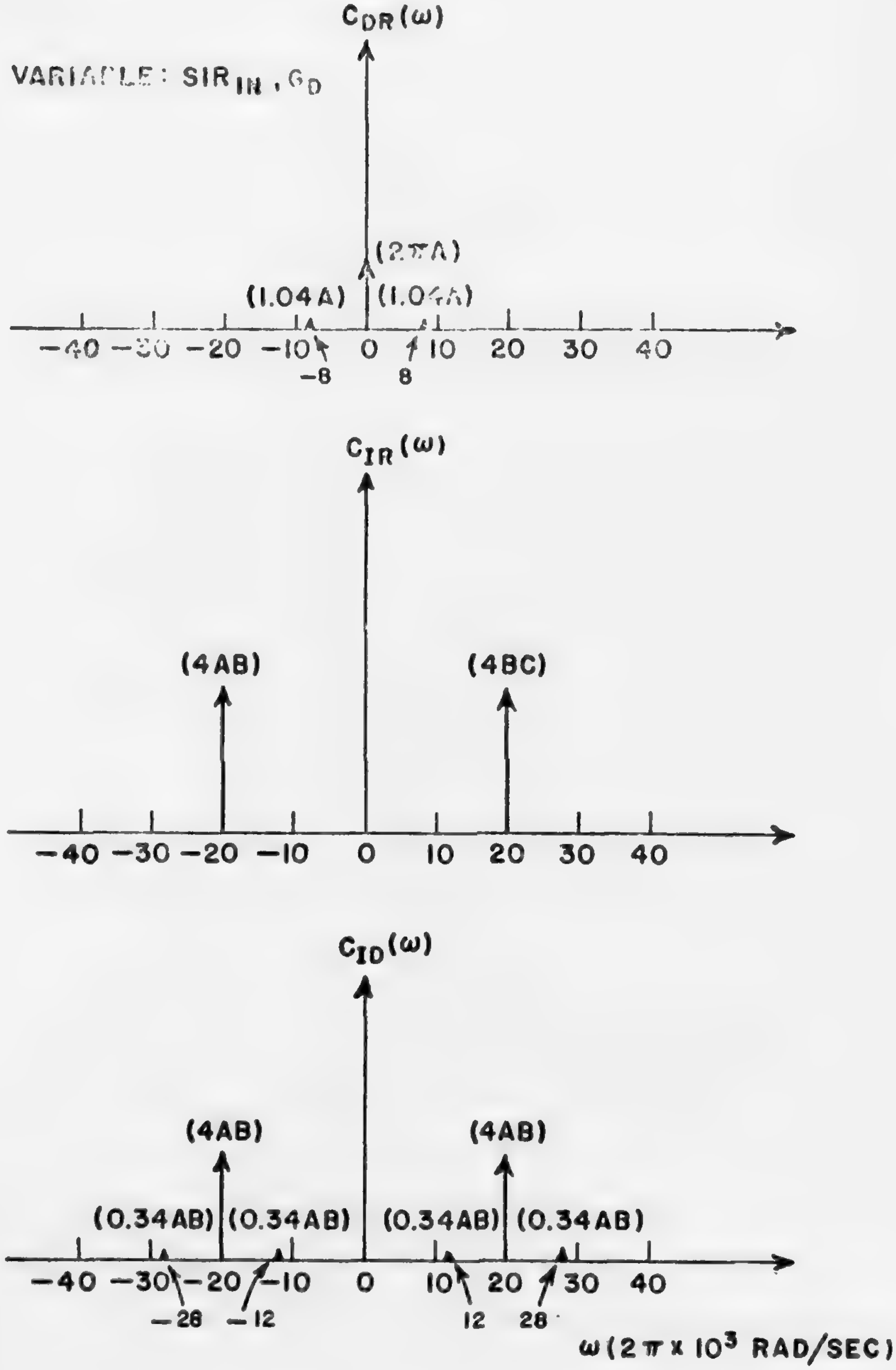

Fig. 6a. Correlation products (SIR_{IN} and G_D varying).

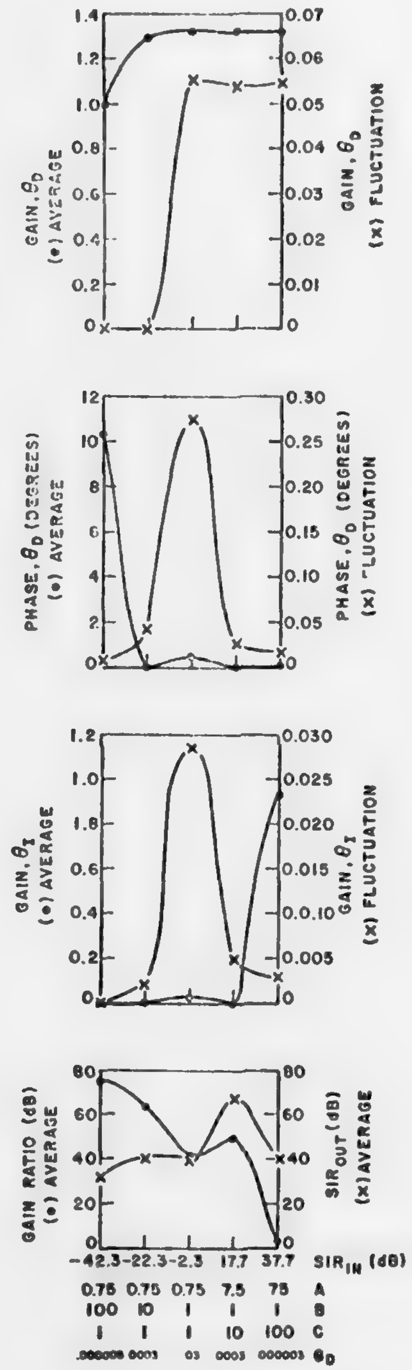

Fig. 6b. Array responses (SIR_{IN} and G_D varying).

(B) FLUCTUATION: Increases as SIR_{IN} increases. This is attributed to the fact that the components of the desired signal in the various correlation products are those closest to dc. As SIR_{IN} increases the amplitudes of these components increase and therefore for a fixed feedback loop bandwidth the level of fluctuation increases.

(b) PHASE, θ_D

(A) AVERAGE: Decreases as SIR_{IN} decreases.

(B) FLUCTUATION: Maximum occurs when the power in the interference and desired signals are almost equal.

(c) GAIN, θ_I

(A) AVERAGE: Increases as SIR_{IN} increases.

(B) FLUCTUATION: Maximum occurs when the powers in the interference and the desired signal are almost equal.

(d) GAIN RATIO AND SIR_{OUT}

(In this case SIR_{IN} is a variable.)

(A) AVERAGE GAIN RATIO: Decreases as SIR_{IN} increases.

(B) AVERAGE SIR_{OUT}: Increases as SIR_{OUT} increases.

In general, array performance improves as SIR_{IN} increases.

IX. WORST CASES

In this section we examine the array performance in the worst case situation when $\omega_p = |\omega_\Delta|$. ω_p and ω_I will be varied simultaneously to satisfy this equality. In these cases, the reference and interference signal product contains a dc component, as do also the desired and interference signal products.

The Fourier transforms of the three correlation products of a typical worst case are shown in Fig. 7a. Array responses in different worst cases are given in Fig. 7b.

The array performance is summarized as follows.

(a) GAIN, θ_D

(A) AVERAGE: Minimum occurs when $\omega_p=0$. (Again, this is a degenerate case where the desired and reference signals contain no phase modulation.) As ω_p increases, the average level of GAIN, θ_D increases rapidly to a maximum value when ω_p is near $1/2\ \omega_m$. Note that when $\omega_p = 1/2\ \omega_m$, one of the spectral components in $C_{ID}(\omega)$ becomes a dc component (the component at $-2\omega_p + \omega_m$). As ω_p increases beyond $1/2\ \omega_m$, GAIN, θ_D decreases slightly.

(B) FLUCTUATION: Minimum occurs when $\omega_p=0$. As ω_p increases, the fluctuation increases to a maximum value when ω_p is near $1/2\ \omega_m$.

(b) PHASE, θ_D

(A) AVERAGE: Maximum occurs when $\omega_p=0$. As ω_p increases the average value of PHASE, θ_D decreases rapidly to a minimum when ω_p is near $1/2\ \omega_m$.

(B) FLUCTUATION: Minimum occurs when $\omega_p=0$. As ω_p increases, the fluctuation increases rapidly to a maximum when $\omega_p = 1/2\ \omega_m$.

(c) GAIN, θ_I

(A) AVERAGE: The maximum occurs when $\omega_p=0$. (Without phase switching, the array has little capability to reject the interference.) As ω_p increases GAIN, θ_I decreases to a minimum when $\omega_p=1/2\ \omega_m$. Beyond $\omega_p = 1/2\ \omega_m$, the average level increases slowly.

(B) FLUCTUATION: The fluctuation is small at $\omega_p=0$ and increases to a maximum when $\omega_p=1/2\ \omega_m$.

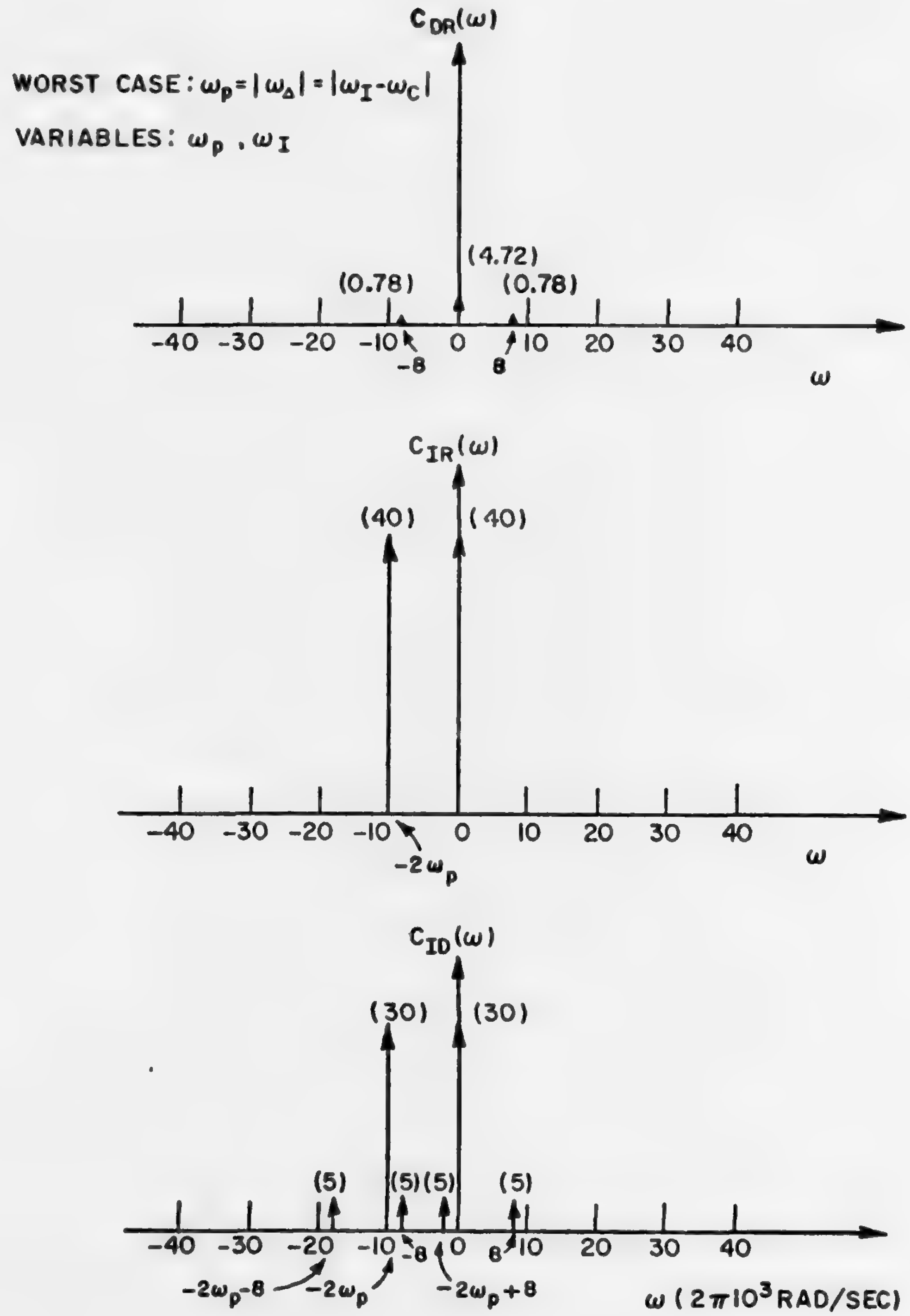

Fig. 7a. Correlation products (worst cases).

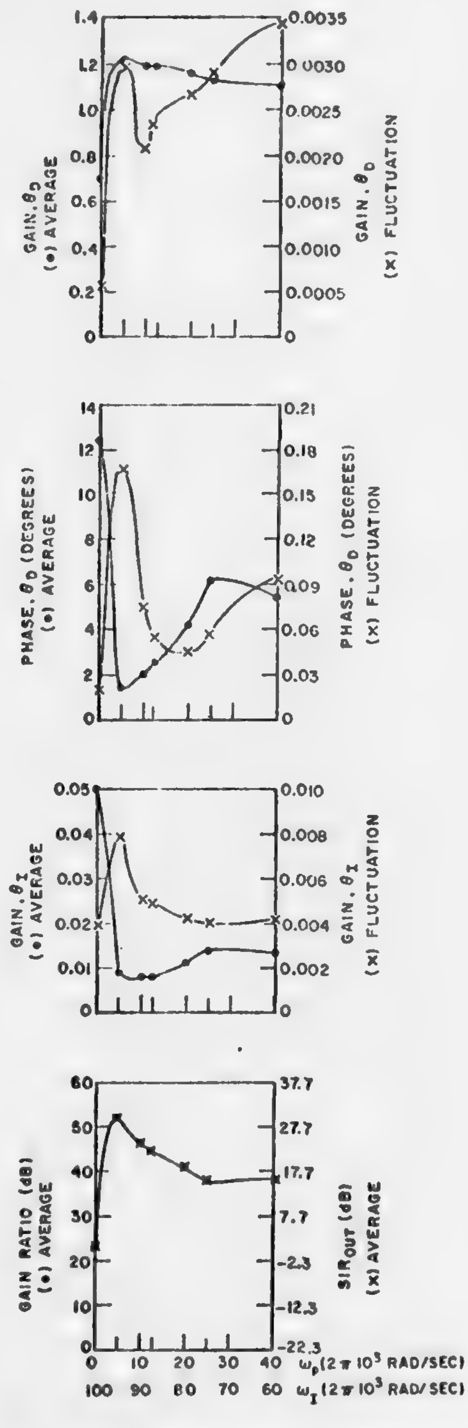

Fig. 7b. Array responses (worst cases).

(d) GAIN RATIO AND SIR_{OUT}

(Since SIR_{IN} is constant for these cases, GAIN RATIO and SIR_{OUT} are related by a constant.)

(A) AVERAGE: The minimum occurs when $\omega_p=0$ and the maximum when $\omega_p = 1/2\ \omega_m$.

In general, for all values of $\omega_p = |\omega_\Delta|$, the performance appears acceptable for reliable AM communications. However, the output SIR drops slight as ω_p is increased.

X. EFFECT OF SIR_{IN} IN A TYPICAL WORST CASE

In this section we study the effect of input signal-to-interference ratio on the array performance under the worst case condition that $\omega_p = |\omega_\Delta|$. Specifically, we choose $\omega_p = 2\pi\ (20 \times 10^3)$ rad/sec, $\omega_I = 2\pi\ (80 \times 10^3)$ rad/sec and $\omega_c = 2\pi\ (100 \times 10^3)$ rad/sec. Also, as SIR_{IN} varies, G_D is also varied appropriately to maintain a constant feedback loop bandwidth.

The Fourier transforms of the three correlation products are shown in Fig. 8a. Array responses are given in Fig. 8b. The curves show that the performance in this situation is poorer than it was in Section VIII, but is still acceptable in most cases. The major difference is that the output signal-to-interference ratio drops more rapidly for low values of SIR_{IN} when $\omega_p = |\omega_\Delta|$ than when $\omega_p \neq |\omega_\Delta|$.

XI. SUMMARY AND CONCLUSIONS

In a companion report[1] a technique for integrating adaptive arrays into conventional AM communication systems was discussed, and some preliminary simulation results were shown. These results indicated that the array will provide suitable interference protection with such signals. The present report shows more extensive simulation results on the effects of the system parameters on array performance. The results indicate that the array can provide suitable protection against CW interference with these AM signals for a wide range of input signal levels.

Interference rejection is slightly poorer at certain critical frequencies. However, the system performance is nevertheless still adequate at these frequencies for reliable communications.

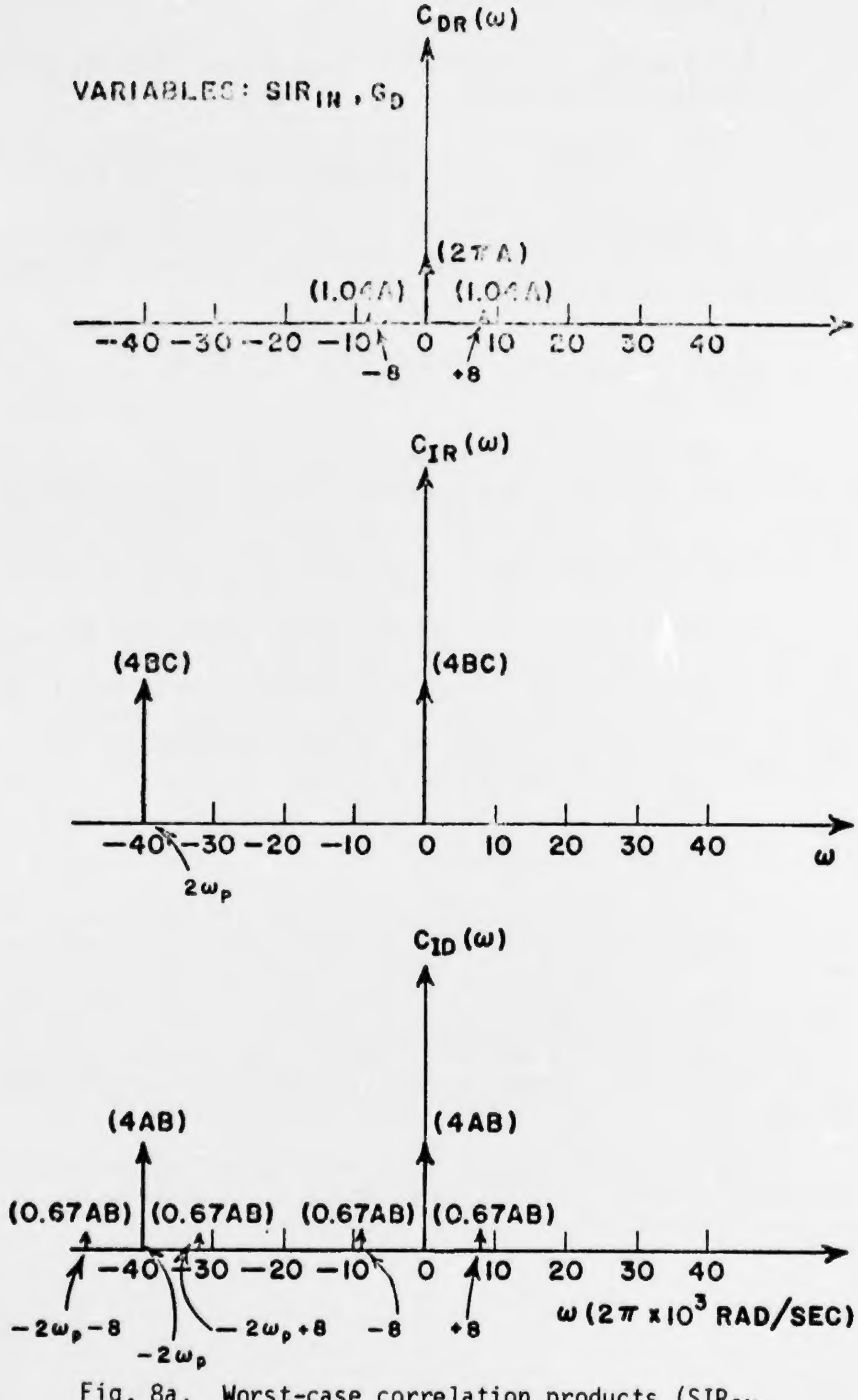

Fig. 8a. Worst-case correlation products (SIR_{IN} and G_D varying).

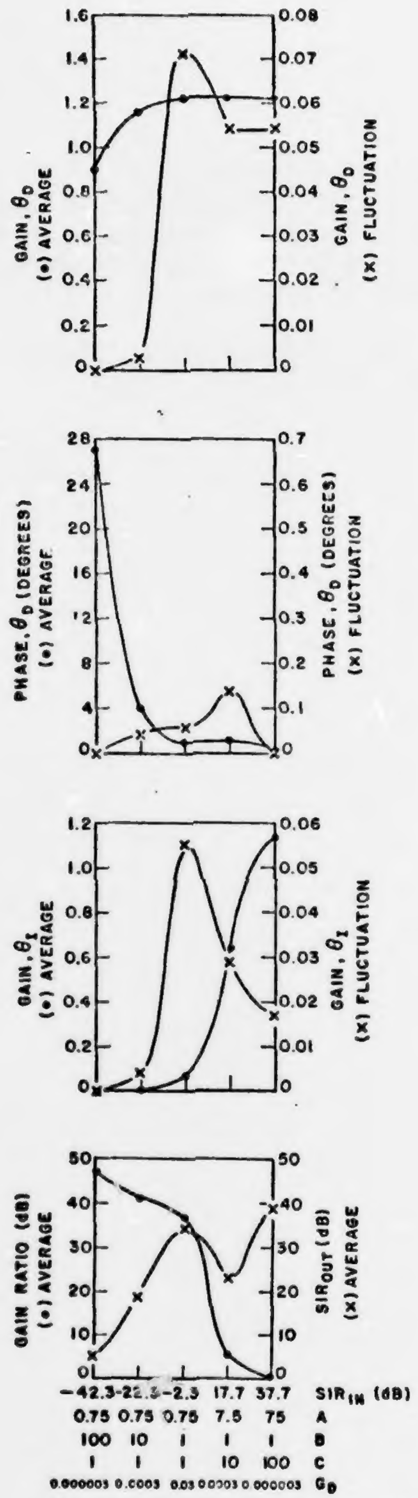

Fig. 8b. Worst-case array responses (SIR_{IN} and G_D varying).

REFERENCES

1. Chan, L.C. and Compton, R.T., Jr., "An Adaptive Array Technique For AM Signals," Report 4326-3, January 1977, The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering; prepared under Contract N00019-76-C-0195 for Department of the Navy.

2. Lathi, B.P., Communication Systems, John Wiley and Sons, Inc., New York, pp. 176-177, (1968).